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16. ABSTRACT

The paper ~~explores the extent to which~~ is about alternative chemicals ~~may find substitution in various applications and the ramifications of such substitution on future atmospheric emissions~~. This substitution, of less ozone-depleting chemicals wherever it is cost effective and technically feasible, is expected because of anticipated future limitations on production and consumption of the fully halogenated chlorofluorocarbons (CFCs) and halons (fluorocarbons containing bromine atoms) covered by the Montreal Protocol. Certain alternative chemicals (e.g., HCFC-22 and methyl chloroform) are already used in applications other than as CFC substitutes. Projected future consumption of alternative chemicals includes such non-substitution use. Study results indicate that the 50% reduction in weighted CFC/halon consumption (weighted for ozone depletion potential) required by the Protocol in 1998 could initially be achieved by alternative chemicals alone. However, alternative processes or products not requiring either the controlled substances or their substitute chemicals and/or substantial recovery and reuse of the chemicals would be needed to maintain the 50% level of reduction in the longer term. The study also shows that the weighted consumption of alternative chemicals could eventually approach that of the controlled compounds if the latter is maintained at the 50% of 1986 level.

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IMPLICATIONS OF THE MONTREAL PROTOCOL FOR ATMOSPHERIC EMISSIONS OF ALTERNATIVE CHEMICALS

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IMPLICATIONS OF THE MONTREAL PROTOCOL FOR ATMOSPHERIC EMISSIONS OF ALTERNATIVE CHEMICALS

INTRODUCTION

In September 1987, twenty-four countries and the European Economic Community signed the "Montreal Protocol on Substances That Deplete the Ozone Layer." By March 1988, the number of signatories had increased to 31 including the Soviet Union. This Protocol calls for a freeze on the consumption and production of fully halogenated chlorofluorocarbons (CFCs) at the 1986 levels beginning as early as mid-1989 followed by reduction to 80 and 50 percent of 1986 consumption and production levels beginning in mid-1993 and mid-1998, respectively. In addition, a freeze on consumption of halons (fluorocarbons that contain bromine atoms) at the 1986 levels is scheduled to begin 3 years after entry into force of the Protocol. A Party's "consumption," as defined by the Protocol, equals production plus imports minus exports. "Production" is defined as actual production minus the amount of CFCs/halons destroyed. The U.S. Environmental Protection Agency announced, in December 1987, a proposed rule for domestic implementation of the Protocol in full compliance with the Protocol's conditions. Promulgation of the EPA's final rule is scheduled for August 1, 1988.

Anticipated future limitations on production and consumption of the fully halogenated CFCs and halons covered by the Protocol (hereafter referred to as "Protocol compounds") are expected to prompt substitution of these compounds with alternative, less ozone-depleting chemicals wherever it is cost effective and technically feasible to do so. Indeed, some alternative chemicals are already available and may find expanded use almost immediately. Examples of alternative chemicals in this category include hydrocarbons, non-fully halogenated CFCs (HCFCs), other chlorinated organics, and blends of CFCs with other compounds.

Other possible alternative chemicals are not yet commercially available but are undergoing development in anticipation of demand (e.g., HCFC-123, HCFC-141b, and HFC-134a). EPA's Air and Energy Engineering Research Laboratory is performing a preliminary evaluation of additional novel halogenated compounds as possible long-term substitutes for currently used CFCs and halons. In the nearer-term, however, alternatives already available or closer to commercialization may find substantially increased usage. In this paper, we explore the applications in which these alternative chemicals may find utilization and project future use of such chemicals both in the U.S. and globally. Implications of future emissions of these alternative chemicals with regard to stratospheric and ground-level ozone are also discussed. Special attention is given to increased usage of alternative chemicals possessing some, though relatively low, potentials for destroying stratospheric ozone.

Such projections necessarily reflect a great deal of uncertainty for a number of reasons, but nevertheless represent a starting point for predicting possible future impacts upon the atmosphere and the ability to achieve the goals set forth in the Protocol. In its Regulatory Impact Analysis (1) of the proposed CFC/halon regulation, the EPA modeled depletion

of stratospheric ozone as a function of control stringency. Some results of this modelling are depicted in Figure 1.

For the predictions shown in Figure 1 it was assumed that CFC production grew at 2.7 percent per year, that 94 percent of other developed countries and 65 percent of the lesser developed countries participate in the Protocol, and that all participants achieve 100 percent compliance. However, the modelling did not consider either the contributions of alternative chemicals having some (though markedly lower) ozone depletion potentials as part of the baseline (no controls) stratospheric ozone depletion, or the offsetting impact of increased use of such alternative chemicals on mitigation of ozone depletion. Also, the results shown in Figure 1 were derived using a simplified numerical approximation of a one-dimensional atmospheric model developed by Lawrence Livermore National Laboratory (2).

APPROACH

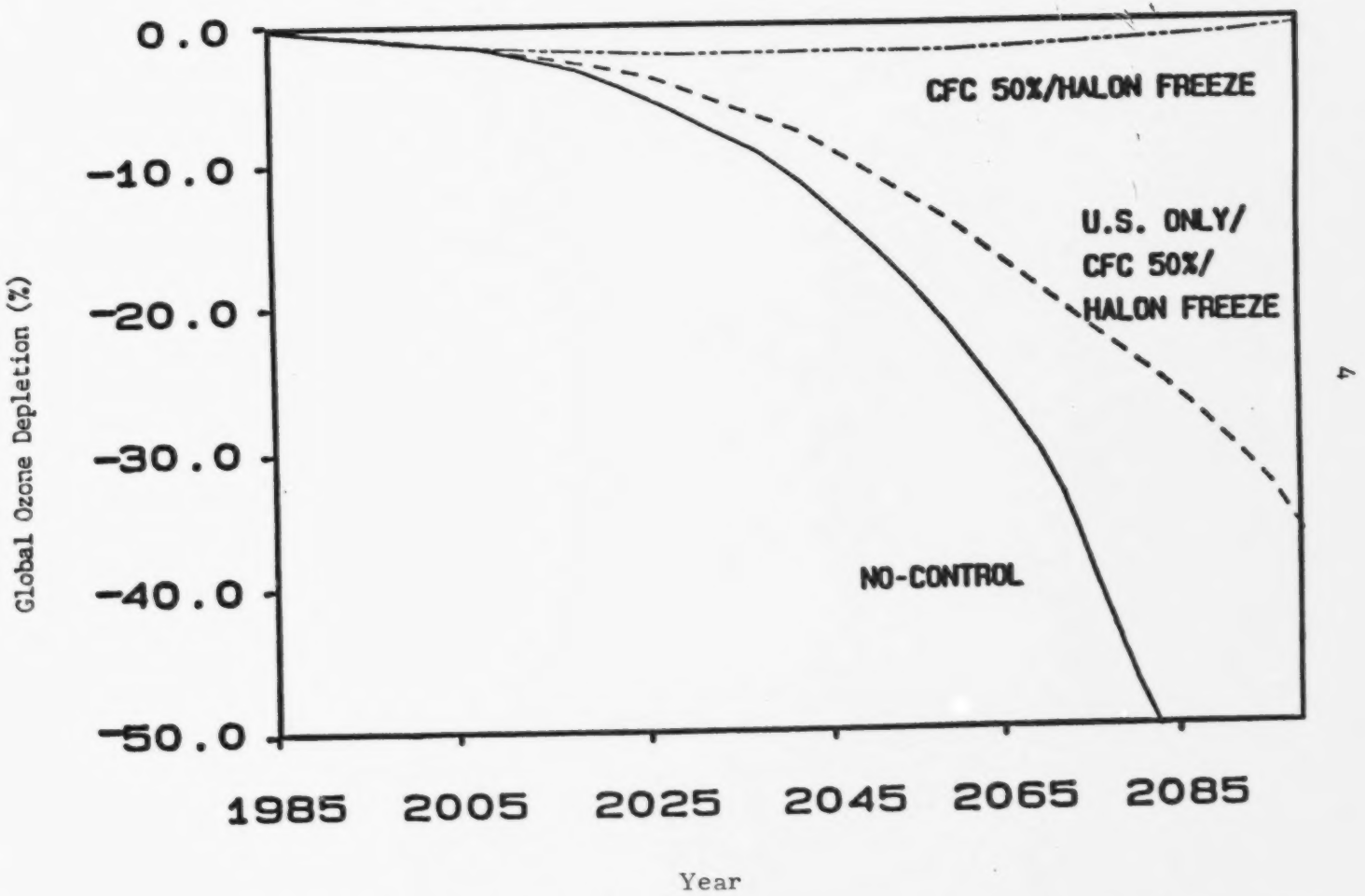
To forecast the impact of the Montreal Protocol on future consumption and emissions of both controlled CFCs/halons and their substitute chemicals, a number of factors must be considered:

- consumption of CFCs/halons over time in the absence of regulation (baseline consumption)
- reduced consumption of CFCs/halons over time assuming the compound coverage and stringency specified by the Montreal Protocol
- baseline consumption of alternative chemicals in non-substitution applications over time
- extent of substitution of alternative chemicals for controlled CFCs/halons over time as influenced by the Protocol's conditions
- release rates of both controlled substances and their substitutes over time

The discussion which follows describes how we estimated the first four of the above factors and gives the results of each determination. Projections of future emissions of both the Protocol compounds and their chemical substitutes are complicated for a number of reasons which we discuss. Nevertheless, we attempt to estimate the potential offset of ozone depletion mitigation posed by substitution of Protocol compounds with low ozone-depleting alternative chemicals.

Baseline Consumption of CFCs/Halons in the Absence of Regulation

As a first step in forecasting future consumption of controlled CFCs/halons and their substitutes, the expected usage of the CFCs/halons in the absence of regulatory intervention must be defined.



Adapted from EPA (1) Figure 1. Global Ozone Depletion Estimate for the No-Control, CFC 50%/Halon Freeze, and U. S. Only Cases

This baseline consumption of the Protocol compounds (CFC-11,-12, -113, -114, -115, and halon-1211 and -1301)* was derived by the EPA in its Regulatory Impact Analysis (1). Since stratospheric ozone depletion is a global phenomenon, the analysis surveyed both U.S. and global consumption.

Each compound may be used in a variety of applications. It is important to define the consumption of each compound in terms of its various end-uses since the growth rate of each end-use differs with time and particular world region, and since emission rates are a function of the type of end-use. Furthermore, some of the potential substitute chemicals are already utilized in applications other than those employing Protocol compounds, and these applications can be expected to grow independently of the CFC/halon uses.

Table 1 lists the 1985 consumption of each Protocol CFC and halon by application category for the U.S. and for the rest of the world as given in the EPA Regulatory Impact Analysis (1). Non-U.S. end-use estimates for CFC-11 and -12 were calculated by subtracting the U.S. estimates from end-use estimates for the world as supplied by the Chemical Manufacturers Association. For CFC-11 and -12, the end-use distribution is markedly different for the U.S. and for other parts of the world owing in large measure to the 1978 U.S. ban on CFCs as non-essential aerosol propellants. Non-U.S. end-use estimates for the other compounds were supplied by various industry sources or were calculated based on the assumption that their market share was the same regardless of world region.

Due to the long atmospheric lifetimes of the fully halogenated CFCs/halons and their cumulative effect upon stratospheric ozone, projections of their consumption and emissions must be extended several years into the future. It should be recognized that such long-term projections necessarily involve considerable uncertainty.

Future usage of the Protocol compounds in the absence of regulations depends on a number of factors including: (a) development of new applications for the chemicals, (b) development of new products or processes that do not use the chemicals, (c) development of markets in the developing countries, and (d) the relationship between chemical usage and level of per capita income. Such projections, attempted by a number of investigators, invariably show a positive correlation with projected economic growth.

Because of this positive correlation, the EPA's projections of both U.S. and global baseline consumption for the seven Protocol compounds (excluding halon-2402) were made for the time period of 1986 to 2050 by applying estimated annual economic growth rates to the base (1986) year consumption. Also, the end-use share for each compound was assumed constant over time.

* Halon-2402, also covered by the Protocol, is not addressed in this paper for lack of data.

Table 1. 1985 Consumption Of Protocol Compounds By Application
U.S./Non-U.S. (10^3 Metric Tons)

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	Halon-1211	Halon-1301
Aerosol	4.5/97.3	7.1/128.8					
Flexible Foam	18.8/45.3						
Rigid PU a Foam	49.7/68.3						
Rigid Non-PU Foam b		9.7/12.2		3.0/6.3			
Refrig-eration	6.6/20.5	85.8/114.4		1.0/2.0	4.5/3.5 c		
Solvent			68.5/98.9				
Fire Suppresant						2.8/3.7	3.5/3.0
Miscellaneous	18.8/d	22.0/d					

(a) Polyurethane

(b) Rigid non-polyurethane foams include polystyrene, polyethylene, and polypropylene.

(c) CFC-115 refrigeration use as CFC-502.

(d) Non-U.S. miscellaneous uses and consumption are unknown.

Table 2 shows the growth rates assumed for each compound for the U.S. and for the world in this baseline analysis. Figure 2 depicts the projected total baseline use of all Protocol compounds together for (a) the U.S. and (b) for the world on a weighted basis. Total weighted consumption is derived by multiplying each individual compound's consumption by the compound's ozone depletion factor and summing the new weighted amounts.

Table 2. Growth Rates of CFCs/Halons in the Absence of Regulation U.S. and Global (Annual Percent)

	1986-1990		1990-2000		2000-2050	
	U.S.	Global	U.S.	Global	U.S.	Global
CFC-11, -12 -114, -115	2.50	3.62	2.50	2.83	2.50	2.50
CFC-113	3.75	4.33	3.75	3.97	2.50	2.50
Halon-1211	9.67	10.24	4.43	5.60	2.75	2.93
Halon-1301	3.38	4.44	-2.47	-1.47	3.27	3.16

Reduced Consumption of Controlled Substances as Required by the Montreal Protocol

Figure 3 shows how the total weighted consumption of controlled CFCs and halons for the U.S. is scheduled to decrease in accordance with the Montreal Protocol. Scheduled decreases for other Protocol Parties would follow the same pattern. Note that reductions from 1986 consumption levels translate into much larger reductions from the projected baseline demand. For example, the 20 percent reduction from the 1986 consumption level scheduled for the year 1993 actually represents a 36 percent reduction from projected 1993 U.S. baseline consumption.

Also note that a 20 or 50 percent reduction in the consumption of each CFC is not necessarily realized in the years 1993 and 1998, respectively, because the Protocol specifies that these percent reductions apply to the total weighted consumption of all controlled CFCs for each Party.

The U.S. EPA is proposing an economic approach to implementing the Protocol. This approach would involve allocating production and consumption "rights" based on 1986 market shares with the allocated amounts totalling no more than the Protocol allows. As the supply of controlled substances is diminished, their prices are expected to rise, and users are then expected to search for less costly alternatives. Other Protocol Parties may or may not adopt such an economic approach.

To project how the consumption of individual controlled compounds would change over time as the Protocol is implemented is, therefore, not

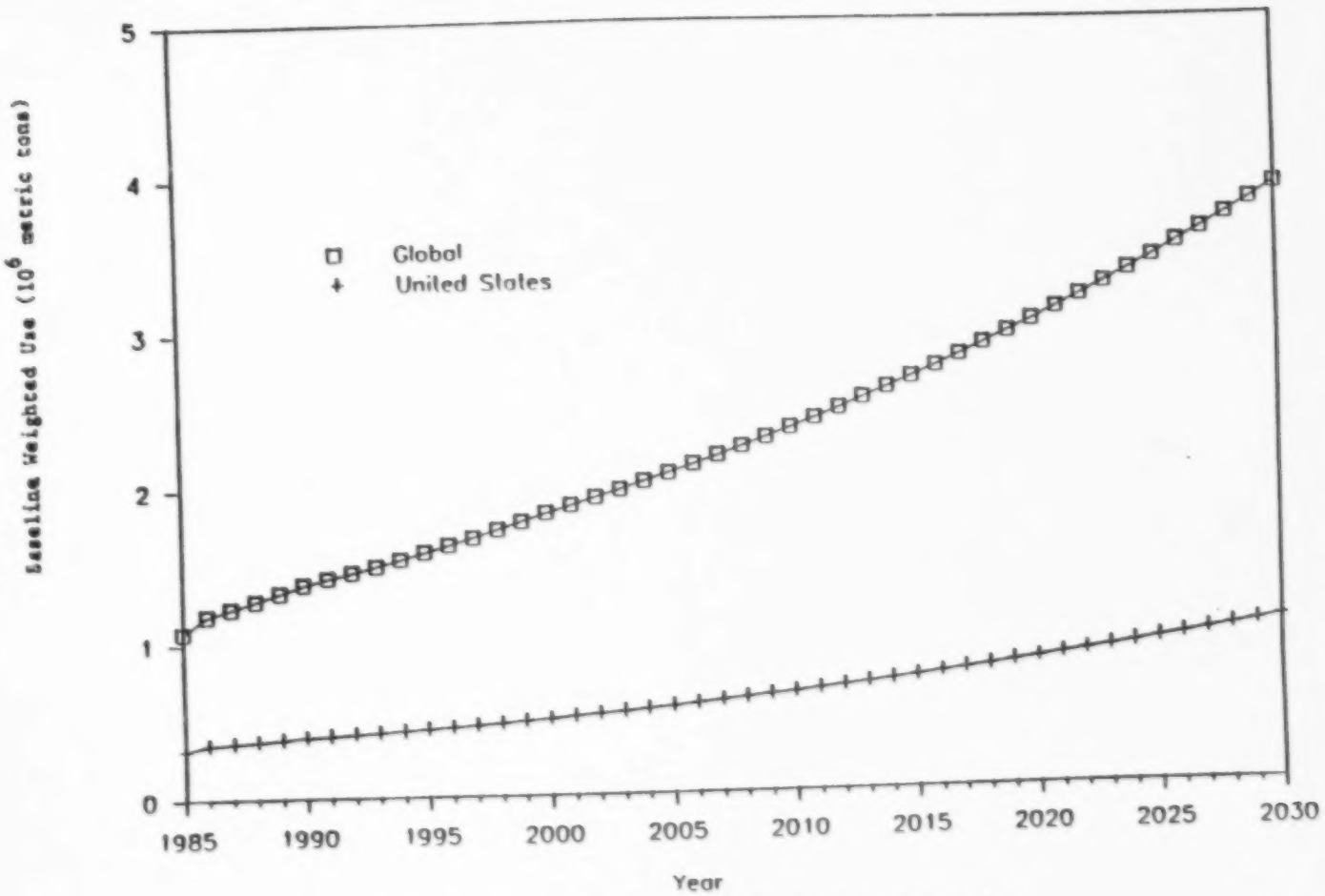


Figure 2. Projected Baseline Weighted Use of Protocol Compounds - U.S. and Global

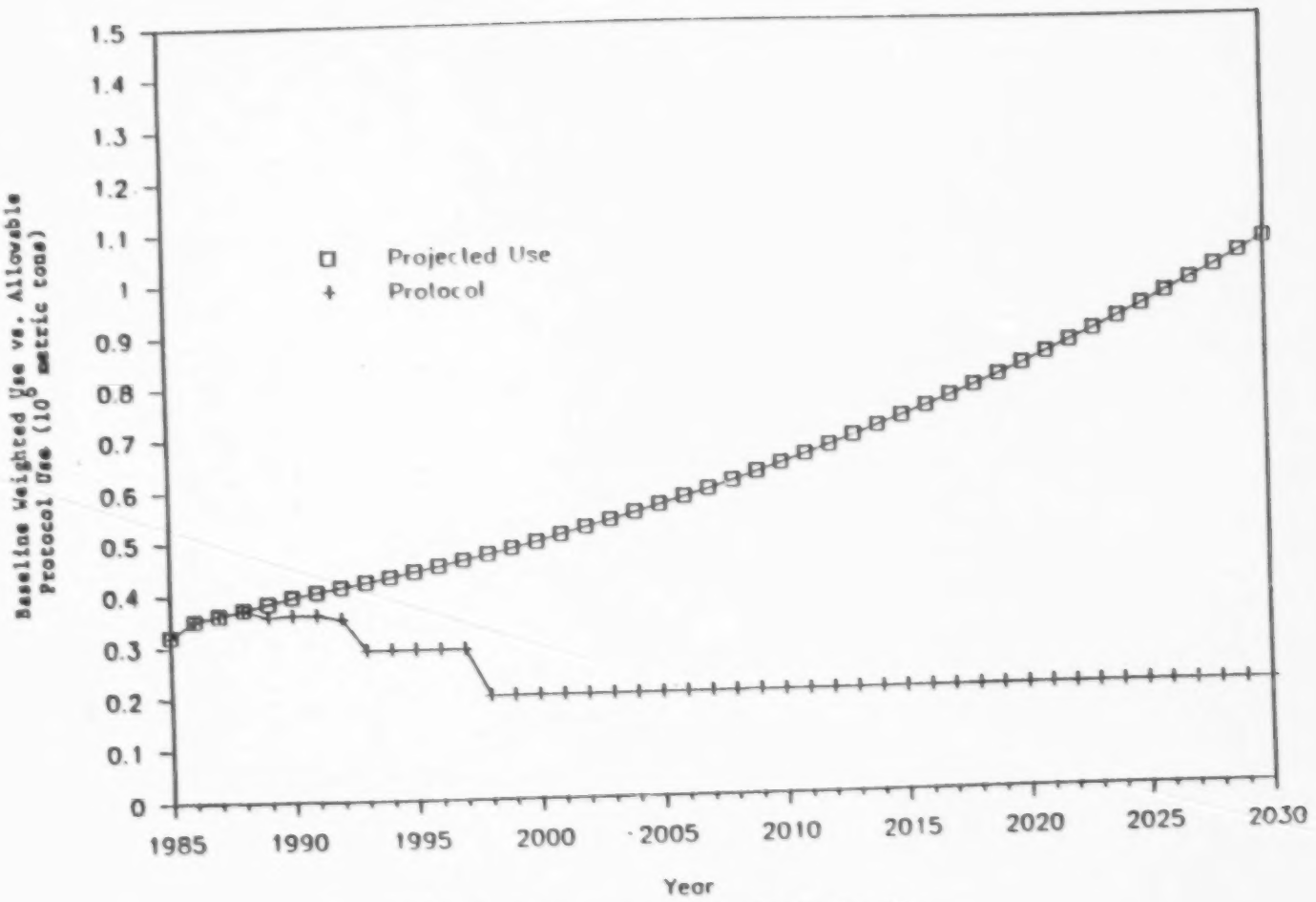


Figure 3. Projected Baseline Weighted U.S. Use of Protocol Compounds vs. Allowable Protocol Use

possible with any reasonable certainty. Such forecasts would involve anticipating the various implementation approaches likely to be taken by each Protocol Party considering such factors as:

- relative social value of each end-use product or application for each world region
- probable annual growth rate for each application over time for each world region based on population and GNP growth
- probable availability of substitute chemicals or products or alternative technologies not requiring the use of controlled substances.

Baseline Consumption of Alternative Chemicals

Table 3 lists those alternative chemicals which, based on our discussions with industry representatives, appear to be the most promising candidates for substitution of Protocol compounds.

Table 3. Alternative Chemicals and Associated Applications

Application	Alternative Chemicals
o Refrigeration (home appliances, water coolers, dehumidifiers, retail food store coolers)	HCFC-22, CFC-502, HFC-134a, HCFC-22/HCFC-142b
o Commercial and Industrial Chillers:	HCFC-22, HFC-134a, CFC-502, HCFC-123
o Mobile Air Conditioning:	HFC-134a
o Rigid Foam Insulation:	HCFC-123, HCFC-141b, HFC-134a
o Packaging Foam:	HCFC-123, HCFC-141b, HCFC-22, CO_2, HFC-124
o Flexible Slabstock Foam:	Methylene Chloride, HCFC-123
o Solvents:	Water, HCs, Alcohols, Chlorinated HCs, New CFC Blends
o Sterilants:	HFC-134a/Ethylene Oxide, 10/90% EO/CO_2, EO/N_2 Purge
o Aerosol Propellants:	HCFC-22/Dimethyl Ether, CO_2

Of particular interest for this study are those alternative chemicals which may possess some potential to deplete stratospheric ozone or to contribute to ground-level ozone. These chemicals and their likely effects are:

- o HCFC-22 (ozone depletion potential = 0.05)*
- o HCFC-123 (ozone depletion potential = 0.04)
- o HCFC-141b (ozone depletion potential = 0.04)
- o HCFC-142b (ozone depletion potential = 0.04)
- o HCFC-124 (ozone depletion potential = 0.04)
- o Methyl chloroform (1,1,1-trichloroethane) (ozone depletion potential = 0.10)
- o Hydrocarbons

Note that for the newer compounds the ozone depletion potentials listed as 0.04 are arbitrarily assigned; tentative values estimated by chemical producers are usually given only as "less than 0.05." We have chosen to use the value of 0.04 in order to have a value for our projections respresentative of a worst-case scenario.

Several of the alternative chemicals listed in Table 3 are already employed in applications other than as substitutes for the Protocol compounds. This is true for HCFC-22, methylene chloride, and all of the solvent alternatives except the new CFC blends. Methylene chloride and other chlorocarbons are used in large quantities primarily as solvents but are not dealt with in this study because they are not known contributors to either stratospheric ozone depletion or to ground-level ozone. An exception is carbon tetrachloride which is assigned an ozone depletion potential of 1.06 and which was considered in our study. However, nearly all of the carbon tetrachloride produced is consumed as a captive intermediate in the production of other compounds including CFCs and is not emitted. Although the use of carbon tetrachloride as a grain fumigant and solvent may grow slightly in certain developing countries, such growth is not viewed as posing a significant threat to global ozone depletion and is not treated further in this study.

While recognizing that certain hydrocarbons such as terpenes and pentane may find increased usage as CFC substitutes as a result of the Montreal Protocol, we believe that increases in their emissions will be small compared to the already large contributions from existing biogenic or anthropogenic sources. Global estimates of hydrocarbon emissions are not only very uncertain but also of limited value since their atmospheric effects tend to be more localized or regional than global.

With regard to stratospheric ozone depletion, it is of interest to define the projected baseline usage (non-substitute usage) of HCFC-22 and methyl chloroform. Accurate current and historical U.S. and global consumptions of HCFC-22 and methyl chloroform are difficult to obtain. Methyl chloroform currently is produced in large quantities around the world and finds major use as a solvent in vapor degreasing and cold cleaning. Smaller amounts of the chemical are also used in aerosols, coatings, and adhesives. Hammitt et al. (3) have estimated 1985

* Ozone depletion potentials are measured relative to a value of 1.0 assigned to CFC-11.

U.S. production at 270,000 metric tons (MT) and world production at 545,000 MT. Projected growth rates for this chemical range from 0.4 to 4.7 percent for the period 1985 to 2040 and reflect various assumptions regarding the influence of increased restrictions on land disposal of chlorinated solvents.

HCFC-22 finds current application as the refrigerant in home air conditioners and in the production of fluoropolymers. In the latter application, the HCFC-22 is consumed as a chemical intermediate and is not emitted. Gibbs (4) has reported the U.S. 1983 production of HCFC-22 to be approximately 110,000 MT with approximately 25 to 35 percent of that amount assigned to fluoropolymer production. SRI (5) estimates 1983 U.S. production of HCFC-22 to be 107,000 MT with 28 percent devoted to polymer manufacture and thus not emitted. Gibbs also estimates 1982 global production of HCFC-22 for applications other than as a chemical intermediate at 139,000 MT (4). The World Meteorological Organization quotes a 1984 global production of HCFC-22 of 206,000 MT (6).

Our estimated U.S. and global growth rates for the potentially stratopheric ozone depleting alternative chemicals are given in Table 4 for the baseline (no regulation) case. Note that only those chemicals which are currently employed in various end-uses are considered since the newer compounds such as HFC-134a and HCFC-123 are not expected to be needed in the absence of regulation.

Table 4. Estimated Baseline Growth Rates for HCFC-22 and Methyl Chloroform - U.S. and Global

Compound	United States	Global
HCFC-22	5%/yr through 1990 [a] 3%/yr for 1990-2050	3%/yr [b]
Methyl chloroform	3%/yr through 1900 [c] 2%/yr for 1990-2050	4%/yr [d]

[a] Short-term growth rate from SRI (5); long-term growth rate from Gibbs (4)

[b] Growth rate from Gibbs (4); also consistent with SRI(5)

[c] Hammitt (3); slightly higher than SRI (5) estimate of 1.5%/yr

[d] Hammitt (3); consistent with SRI (5) estimate of 4-5%/yr in Western Europe

Figures 4 and 5 depict graphically the projected global unweighted baseline consumption of each of these alternative chemicals and the total weighted global baseline consumption, respectively.

Projected Use of Alternative Chemicals as Substitutes for Controlled CFCs/Halons

The actual extent to which each of the alternative chemicals finds utilization as a CFC/halon substitute in each application will be a function of the chemical's availability, cost, technical feasibility, the extent to which other technological advances such as new or modified processes supplant the need for the chemical use, and the particular approach to Protocol implementation adopted by each Protocol Party.

Clearly, to take into account each of the above considerations in projecting the consumption of alternative chemicals would involve much speculation. Since our interest in this study lay primarily with the consequences of replacing regulated CFCs and halons with alternative chemicals, we simplified the procedure by assuming that alternative chemicals would always be implemented wherever technically feasible in preference to any other options. Other control options (e.g., alternative processes or products) are then adopted only to meet any further reductions required to achieve the goals of the Protocol. Such an approach presents a "worst-case" scenario with regard to the quantities of alternative chemicals consumed and emitted to the atmosphere. Further, we adopted the implementation time frames and potential market penetrations for the alternative chemicals as suggested by the EPA in its Regulatory Impact Analysis (1).

Although such a methodology is obviously contrived, it does allow an assessment of the potential use of alternative chemicals sufficient to enable (a) a determination of the extent to which the Protocol goals could be achieved by alternative chemicals alone, (b) a determination of the relative demand for each of the alternative chemicals over time, and (c) a means of estimating the potential relative contributions of the alternative chemicals to future atmospheric emissions.

Table 5 displays the alternative chemical options for each controlled substance in each application along with initial market penetration levels, ultimate penetration levels, and time to achieve ultimate penetration. Determination of these levels and times is often quite speculative, and (for the less obvious cases) the following explanations are offered:

- CFC-115 Use: By far, the predominant use of CFC-115 is as one component of the binary azeotrope CFC-502 (49 percent HCFC-22 and 51 percent CFC-115 by weight). 1985 U. S. consumption of CFC-502 has been estimated at 9200 metric tons (1). Since CFC-502 has a much lower ozone depletion factor than CFC-12, it is expected to enjoy increased use as a result of regulation. More specifically, CFC-502 will likely replace CFC-12 in new retail food coolers, cold storage warehouses, and in some hermetic systems. In this analysis, the projected increased usage of CFC-502 was apportioned between the components, CFC-115 (as a Protocol compound) and HCFC-22 (as an alternative

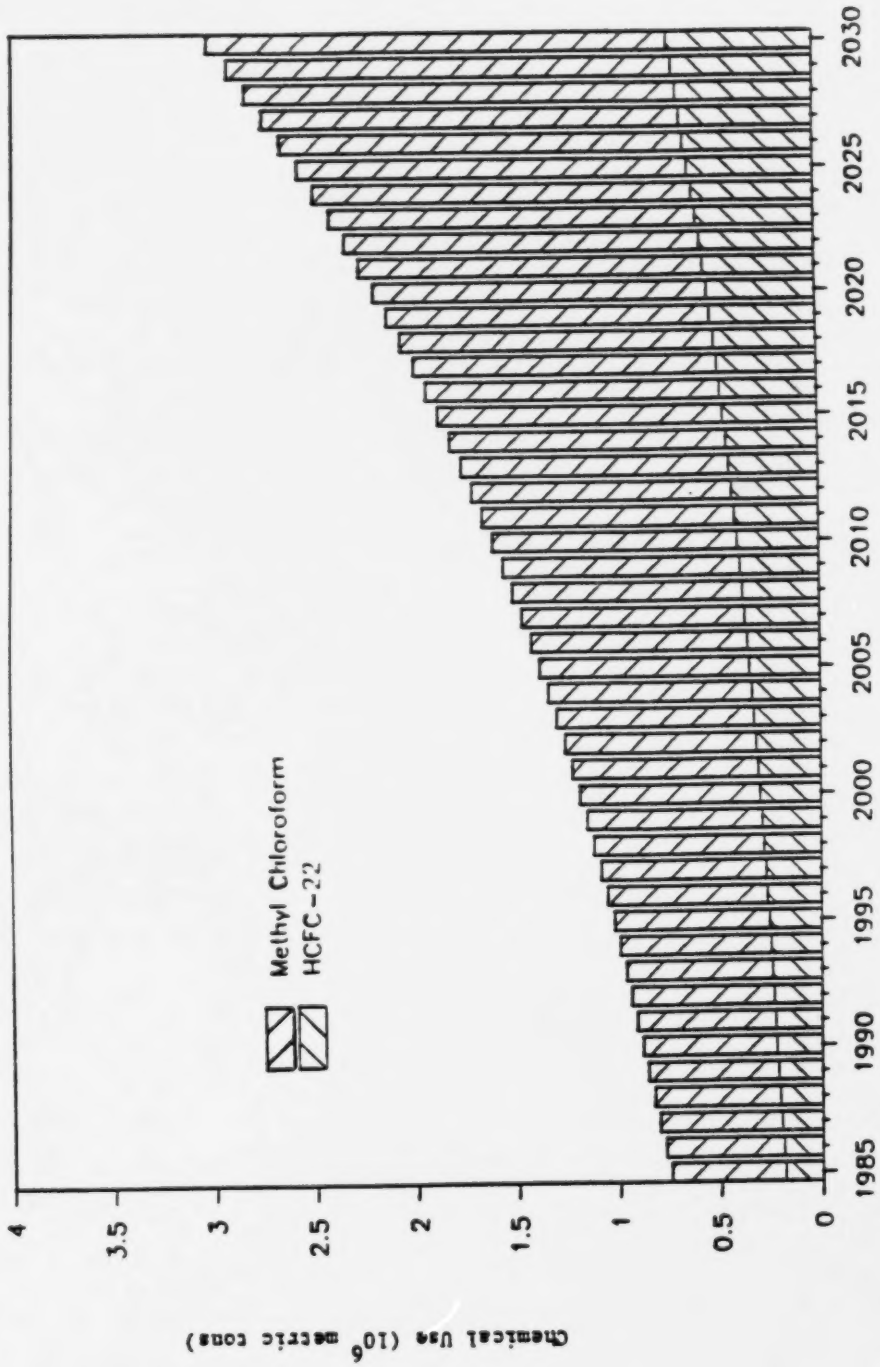


Figure 4. Unweighted Baseline Use of HCFC-22 and Methyl Chloroform - Global

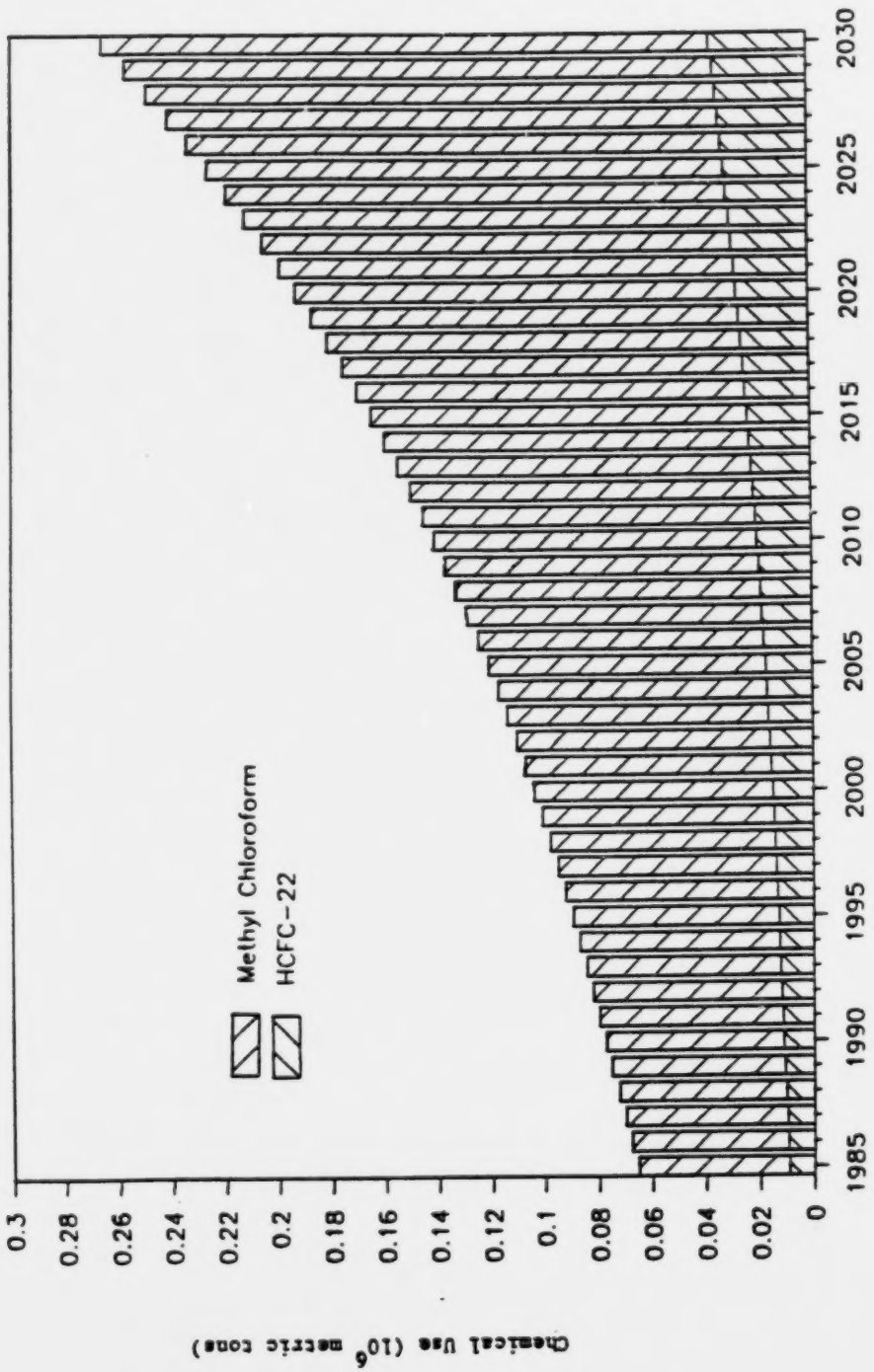


Figure 5. Weighted Baseline Use of HCFC-22 and Methyl Chloroform - Global

Table 5. Alternative Chemical Options

Compound	Application	Percent Compound Use in Application		Control Options	Availability (ST, MT, LT)[a]	Initial Penetration (percent)		Implementation Time (years)		Ultimate Penetration (percent)	
		U.S.	Rest of World			U.S.	Rest of World	U.S.	Rest of World	U.S.	Rest of World
CFC-11	Aerosol	5.7	38.9	HCFC-22/DME Blend	ST	50	10	1	7	50	70
	Centrifugal Chillers	8.3	8.2	HCFC-22	ST	13	13	20	20	90	90
	Rigid PU b Foam (board-stock, poured, and sprayed)	62.4	27.3	HCFC-123	LT	15	15	3	3	45	45
				HCFC-141b	LT	15	15	3	3	45	45
	Flexible PU Foam (slabstock)	18.3	14.1	HCFC-123	LT	5	5	10	10	45	45
				HCFC-141b	LT	5	5	10	10	45	45
CFC-12	Aerosol	5.2	46.6	HCFC-22/DME	ST	50	10	1	7	50	70
	Centrifugal Chillers	2.9	2.6	HCFC-22	ST	13	13	20	20	90	90
	Cold Storage/Retail Food	6.7	18.6	HCFC-502	ST	5	5	10	10	50	50
				HFC-134a	LT	5	5	10	10	50	50
	Hermetic Systems	3.3	9.2	HCFC-22/HCFC-142b	MT	3	3	3	3	10	10
				HCFC-502	MT	10	10	3	3	30	30
				HFC-134a	LT	20	20	3	3	60	60
	Mobile Air Conditioning	49.8	11	HFC-134a	LT	10	10	10	10	100	100
	Rigid PS c Extruded Sheet	4.5	3.0	HCFC-22	ST	20	20	3	3	60	60
	Rigid PS Boardstock	2.1	1.4	HFC-134a	LT	20	20	3	3	70	70
	Sterilants	8.9	--	HFC-134a	LT	1.2	--	8	--	10	--
	Miscellaneous	1.8	--	HCFC-22/DME	ST	50	--	1	--	50	--
CFC-113	Solvent	100	100	Methyl Chloroform	ST	5	5	5	5	25	25
				Terpene	ST	5	5	5	5	25	25
CFC-114	Centrifugal Chillers	23.8	23.8	HCFC-22	ST	13	13	20	20	90	90
	Other Foam (PE d & PP e)	76.2	76.2	HCFC-124	LT	20	20	3	3	70	70
Halon-1301	Fire Extinguisher Discharge Test Losses	8.5	8.5	HCFC-22	ST	30	30	3	3	95	95

Note: CFC-115 and Halon-1211 are not included; CFC-115 is considered to be an alternative chemical when used as CFC-502, and no chemical substitutes for Halon-1211 were presented in the R.I.A.

a ST = Short term (0-3 years); MT = Mid Term (4-7 years); LT = Long Term (7+ years) starting from 1985.
b Polyurethane
c Polystyrene
d Polyethylene
e Polypropylene

chemical). It is important to note that any increase in CFC-115 use would require that other Protocol compounds take even further reductions so that a Protocol Party's overall weighted use remains in compliance.

- Aerosols: Potential reductions in aerosol use are different for the U. S. and for the rest of the world. For the U. S. it was assumed that 50 percent of the present regulatory-exempt aerosol applications could convert to HCFC-22/Dimethyl Ether (DME). Further, it was assumed that this conversion could be accomplished in 1 year. Our reasoning is that some of the exempt "essential" aerosol applications may now have alternatives (such as HCFC-22/DME) that were not available when the exemptions were granted in 1978. The short conversion time reflects the fact that this is a relatively small segment of use in the U. S.

  For the rest of the world, it was assumed that 70 percent of the current use of CFC-11 and -12 in aerosols could be reduced by using HCFC-22/DME. Further, it was assumed that this conversion would require 7 years. The reasoning behind these assumptions is that there will likely be a large substitution away from current CFC propellants such as occurred in the U. S. when the 1978 regulation entered into force (a reduction of approximately 95 percent). While other countries may not reduce their CFC use in aerosols to this extent (note that the European Economic Community has already taken steps to attain partial reduction in such usage), it is generally felt that aerosol uses would be among the first to switch to alternatives. Our estimate of 70 percent conversion to HCFC-22/DME again reflects a maximum ultimate penetration for this chemical alternative since other options (such as the use of hydrocarbon propellants and pump sprays) are also probable. The time for conversion was lengthened relative to the U. S. case due to the much higher volume of use to be converted.

- Mobile Air Conditioning: This application is a major consumer of CFC-12. Only one chemical alternative, HFC-134a, was considered for this end-use because of information obtained from motor vehicle manufacturers. Other possible substitutes which have been discussed include HCFC-22 (either alone or as a blend) and hydrocarbons. However, the consensus from U. S. automakers seems to be that HFC-134a is the first choice. Our estimated implementation schedule for HFC-134a is based on the assumption that 10 years would be needed to fully convert to a new refrigerant in new vehicles beginning in the year 1993.

- Chillers: It was assumed that 40 percent of future refrigerant demand for chillers could be filled by HCFC-22 in conjunction with screw compressors. However, due to the long useful lives of both existing units and the remaining 60 percent of new demand which would still require service with CFC-11, -12, and -114, we assumed 20 years would be needed to fully implement HCFC-22 substitution in this application.

- Rigid Polyurethane Foam: For this application, two possible chemical alternatives were considered most likely to be implemented: HCFC-123 and -141b. At the time of this study, neither chemical had been fully tested and proven acceptable. Hence, we divided the penetration levels equally between the two chemicals and assigned equal implementation times to each. The 3 years to reach ultimate penetration once the alternatives were available was based on an assumed 2 year product development and 1 year conversion timescale. It was further assumed that HCFC-123 and -141b would be substituted for CFC-11 on a one-to-one molar basis, an assumption which was made for every chemical alternative in every application.

- Flexible Polyurethane Foam: This application consists of two industrial segments - slabstock and molded foam. The molded foam segment is expected to continue to move away from CFC-11 usage as such foams are already largely produced with "water-blown" formulations. For production of slabstock foam we assumed that both HCFC-123 and -141b could be alternatives and assigned each chemical equal market shares and implementation times. A time of 10 years beginning in 1993 was used to achieve ultimate penetration to reflect the large number of manufacturing facilities and the belief that most manufacturers have limited assets to reformulate, test, and convert to a new blowing agent.

- Solvents: For this study, only two chemical alternatives were considered owing to their potential for perturbing stratospheric or ground-level ozone: methyl chloroform and such hydrocarbons as terpenes. Both substitutes were assumed to each garner only 25 percent of the current demand for CFC-113 and each was assumed to take 5 years to reach that penetration level.

- Other Foams: HFC-124 was considered to be the most likely replacement for CFC-114 as a blowing agent in the manufacture of polyethylene and polypropylene foams. The implementation time was assumed to be the same as for HFC-134a in rigid polystyrene foam boardstock; i.e., 2 years for product development and 1 year for conversion commencing in the year 1993.

- Fire Suppressants: Because of the halons' unique fire extinguishing properties, no chemical alternatives have been suggested. However, it has been proposed that HCFC-22 be used in place of halon-1301 as a substitute for testing total flooding systems. The penetration levels and implementation times adopted for our study were taken from the EPA's Regulatory Impact Analysis (1).

Figures 6 and 7 indicate the possible growth of each alternative chemical owing to its substitution for currently used CFCs/halons for the U.S. and globally, respectively.

Figures 8 and 9 show how the collective substitution of Protocol compounds with these alternative chemicals (per the Table 5 conditions) reduces the projected weighted U.S. and global baseline consumption of

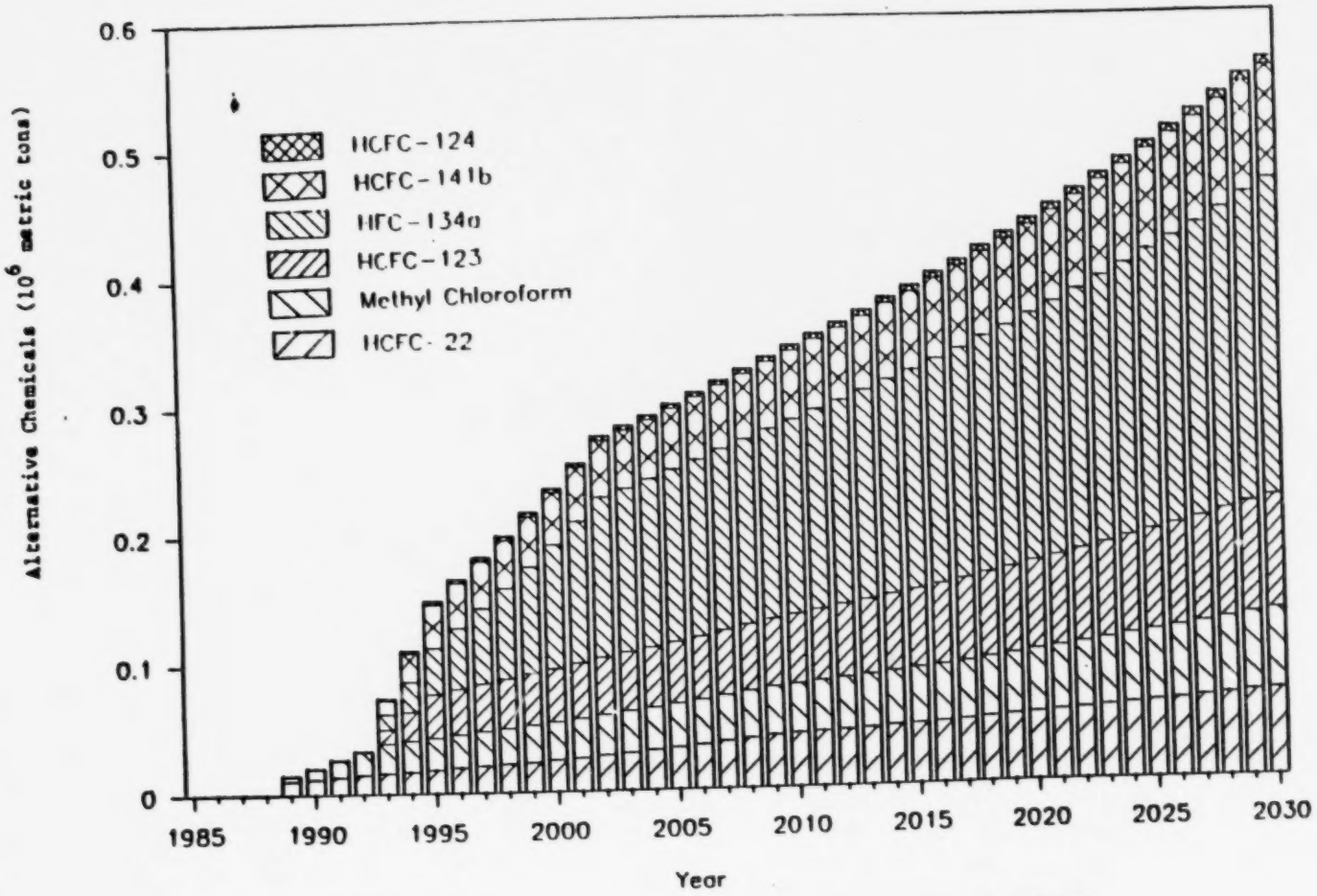


Figure 6. Unweighted Use of Alternative Chemicals as Substitutes for Protocol Compounds - U.S.

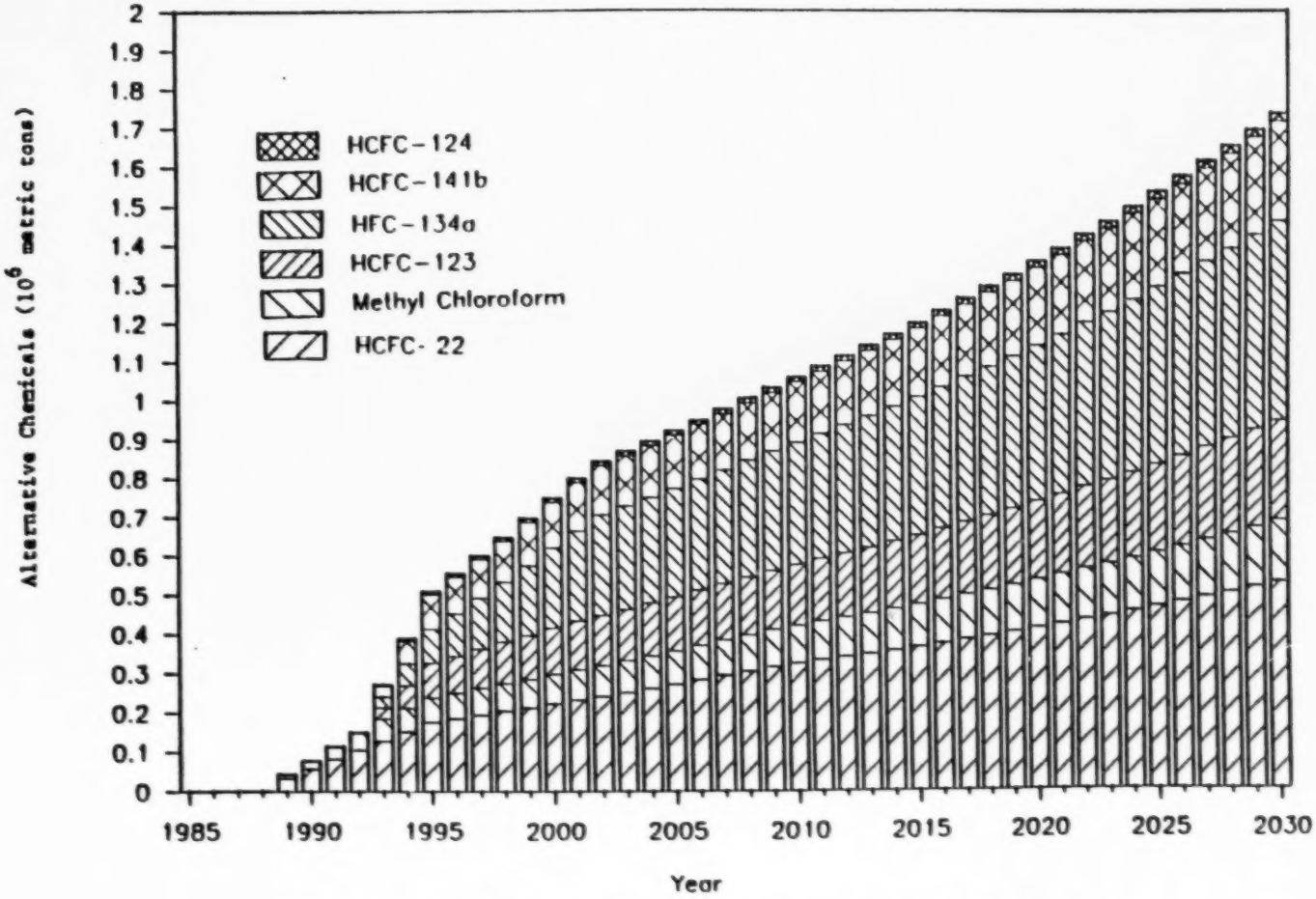


Figure 7. Unweighted Use of Alternative Chemicals as Substitutes for Protocol Compounds.- Global

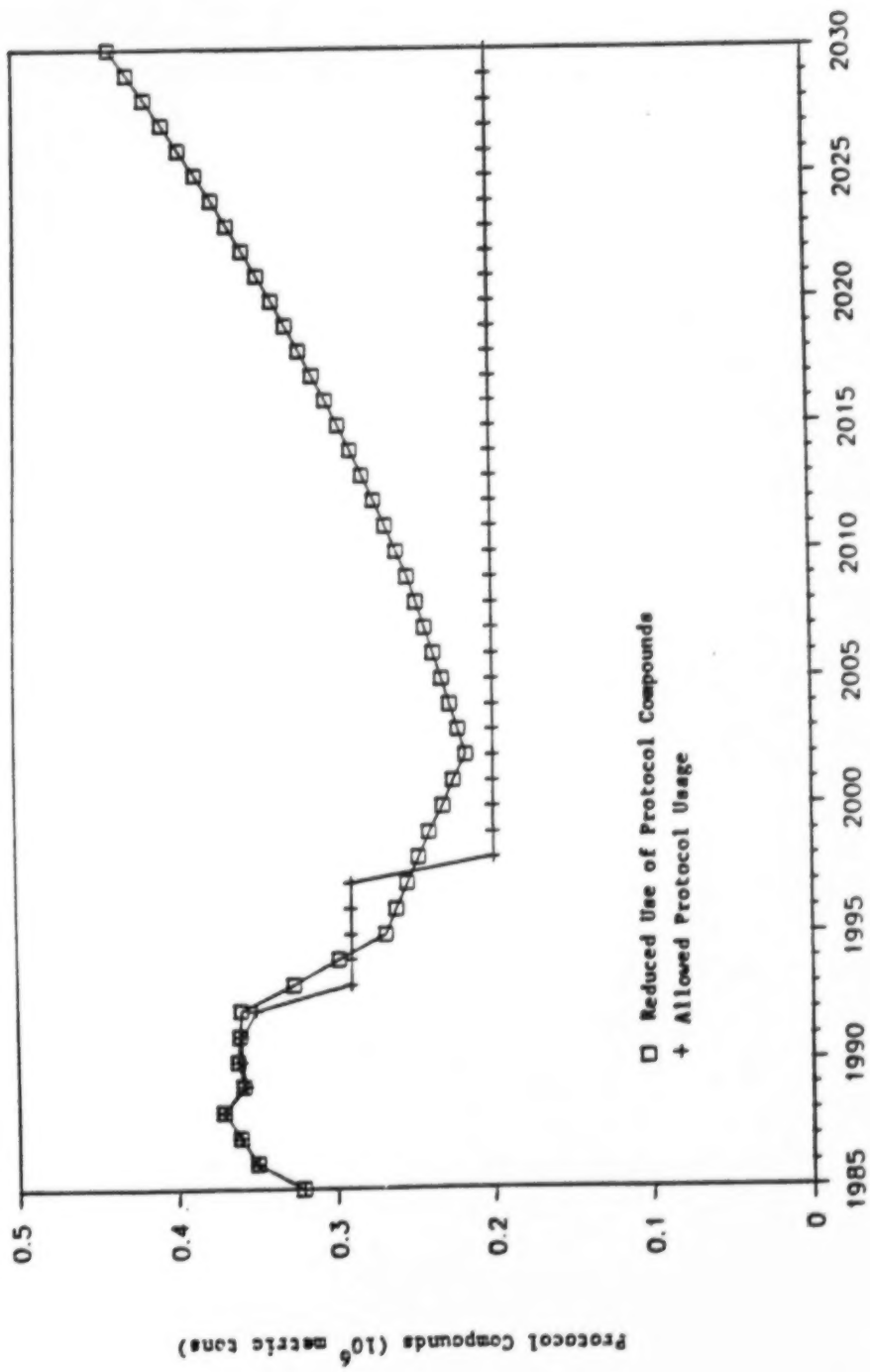


Figure 8. Weighted Use of Protocol Compounds After Substitution of Alternate Chemicals - U.S.

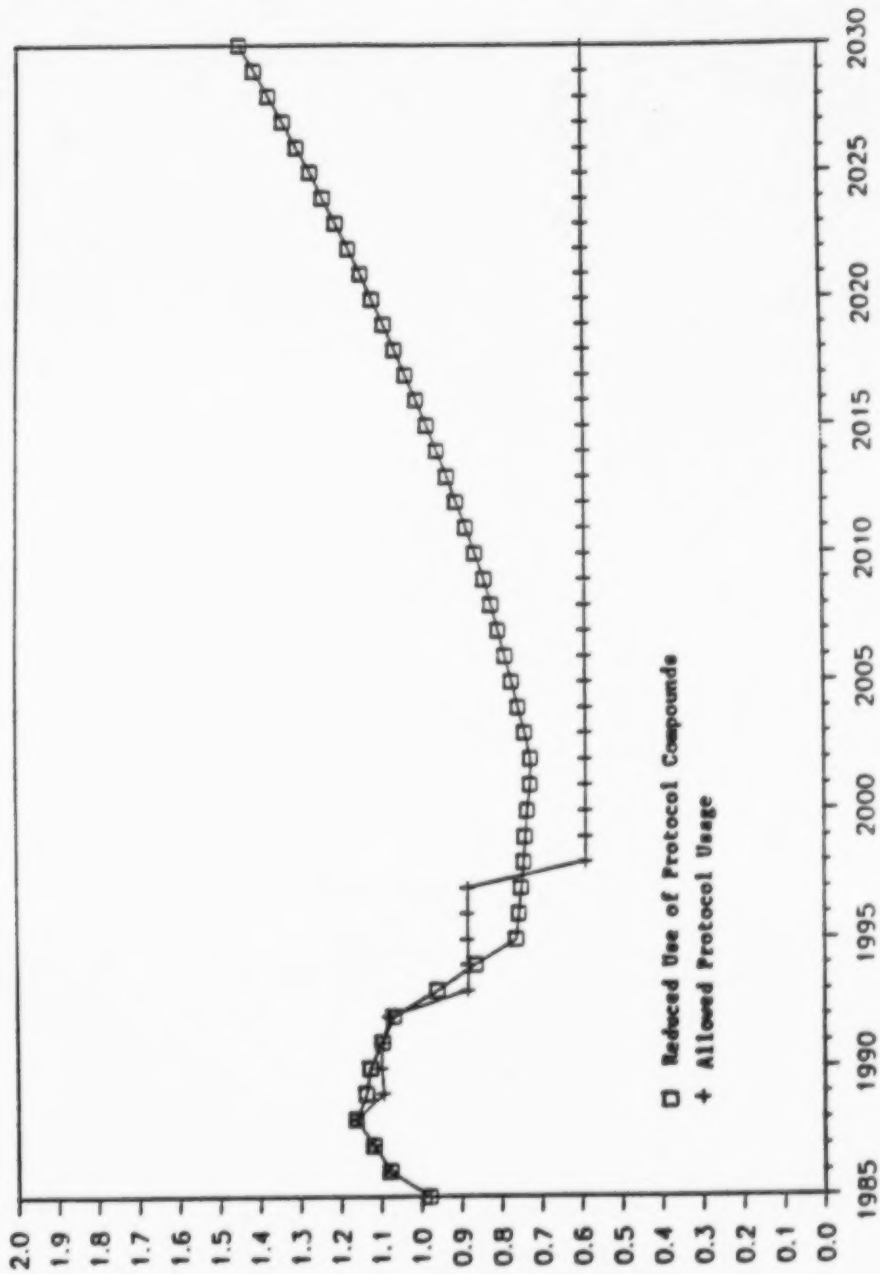


Figure 9. Weighted Use of Protocol Compounds After Substitution of Alternate Chemicals - Global

the controlled substances, respectively.

RESULTS AND CONCLUSIONS

Inasmuch as the approach employed in this study assumed the implementation of alternative chemicals as the control option of first choice in every application wherever technically feasible, and did not allow for reductions in demand of either the Protocol CFCs/halons or their substitutes due to the introduction of alternative products or processes, the approach tends to maximize the growth of alternative chemicals. Also, our approach assumed that no insurmountable technical difficulties would be encountered in the commercialization or implementation of the newer chemicals such as HCFC-123, HCFC-141b, or HFC-134a. Actual future consumption of any of the alternative chemicals may differ significantly from our projections, but will not likely be greater than the amounts we have derived.

In Figures 8 and 9 it is noted that the reduction in use of Protocol compounds achieved by substitution of alternative chemicals alone is sufficient or nearly so to achieve the Protocol goals, at least until approximately the year 2003. This result appears to be more optimistic than that suggested previously by the Alliance For Responsible CFC Policy (7). However, the Alliance's predictions considered the implementation only of currently unavailable alternatives HCFC-123, HCFC-141b, and HFC-134a. Although our results are possibly somewhat overstated in the opposite sense, our study shows that currently available alternative chemicals could bring about significant reductions in Protocol compound usage in the near- and mid-term.

Also to be noted in Figures 8 and 9 is that the demand for controlled substances decreases initially when substitutes are first implemented but begins to increase again after the year 2003. This apparent anomaly is based on (a) the fact that the reduced usage is derived from the projected baseline usage of Protocol compounds which continually grows in the absence of regulations, and (b) the fact that for some applications 100 percent substitution of alternative chemicals was not deemed feasible or else requires a very long time to reach ultimate penetration.

In actuality, the demand for Protocol compounds will likely be lessened by the introduction of new processes and products not requiring the use of either the regulated chemicals or chemical substitutes. For example, the use of CFC-11 is already rapidly diminishing in the production of molded flexible polyurethane foam, not as a result of employing substitute auxiliary blowing agents, but as a result of eliminating the need for an auxiliary blowing agent entirely. Another example would be switching to pump sprays to replace the need for aerosol propellants.

Additional reduction in the future demand for Protocol compounds is also expected to be achieved by the practices of recovery, reclamation, and reuse of such compounds. In particular, substantial improvement in the conservation of Protocol compounds seems possible by recovery and reuse of refrigerants from chillers and retail food store food coolers during equipment servicing or decommissioning and by reclamation and reuse of waste solvents.

It is of interest to consider the offsetting contribution of some of the alternative chemicals to the projected mitigation of stratospheric ozone depletion. Previous EPA derivations of the mitigation of ozone depletion achievable by the Montreal Protocol did not account for the influence of alternative chemicals possessing some small ozone depletion potential.

A thorough analysis of the potential contribution to depletion of stratospheric ozone by the alternative chemicals requires the use of an atmospheric model in conjunction with projected emissions of each alternative compound. These projections must take into account any current and past "banked" quantities of these chemicals in end-uses where the chemical is slowly emitted to the atmosphere, the future growth in use of the alternative chemicals in both substitute and non-substitute applications, and the rate of release in future applications. Such difficult projections are complicated even more by a very inadequate understanding of the current and past end-use allocations of such chemicals as HCFC-22. Our initial investigations have indicated a large discrepancy between the historical production of HCFC-22 and known end-use consumption.

Lacking good emissions estimates for HCFC-22 from past banked sources, we attempted to estimate the potential offsetting contribution of low-ozone depleting substitute chemicals to global ozone depletion mitigation by comparing the projected weighted use of alternative chemicals with the avoided consumption of Protocol compounds. Figure 10 depicts the projected total weighted reduction in global usage of Protocol compounds achievable by substitution with alternative chemicals compared to the total weighted use of alternative chemicals from substitution applications alone. Figure 11 shows the same type of comparison except that the projected total weighted use of alternative chemicals includes both substitution and non-substitution applications.

This simple approach indicates that the potential offsetting effect of low-ozone depleting chemicals (ozone depletion potential of 0.1 or less) toward mitigation of stratospheric ozone depletion is on the order of 20 percent by the year 2000 when one considers increased consumption of these chemicals in both CFC substitute and non-substitute applications. Again, the extent to which the pre-1986 bank of HCFC-22 and methyl chloroform adds to the offset has not been taken into account.

Finally, our projections (Figure 11) show that by the year 2030 the total weighted world use of low ozone-depleting alternatives is nearly 470,000 MT, a figure approaching the approximate 600,000 MT of regulated CFCs and halons allowed for all Protocol Parties together under the 1987 Protocol (see Figure 9). Thus, the contribution of the alternative chemicals to stratospheric ozone depletion could eventually become as great as that still contributed by the controlled substances, essentially doubling the overall depletion. Again, it must be emphasized that our analysis is contrived to give a "worst case" for consumption of alternative chemicals and does not allow for other means of CFC/halon control such as alternative products and processes which can reasonably be expected to substantially reduce the need for both regulated and substitute chemicals.

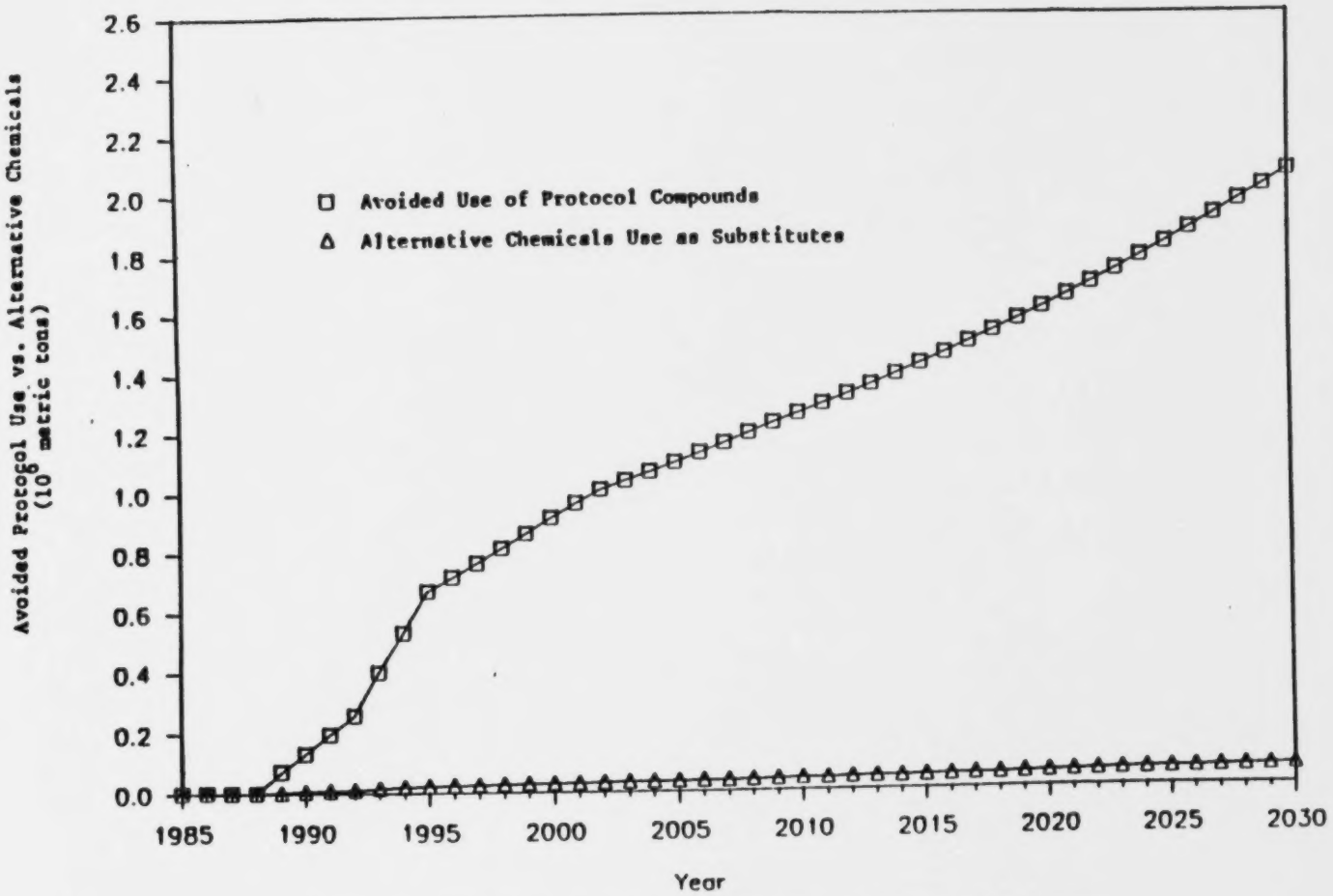


Figure 10. Comparison of Weighted Metric Tons of Protocol Compounds Avoided and Weighted Metric Tons of Alternate Chemicals as Substitutes

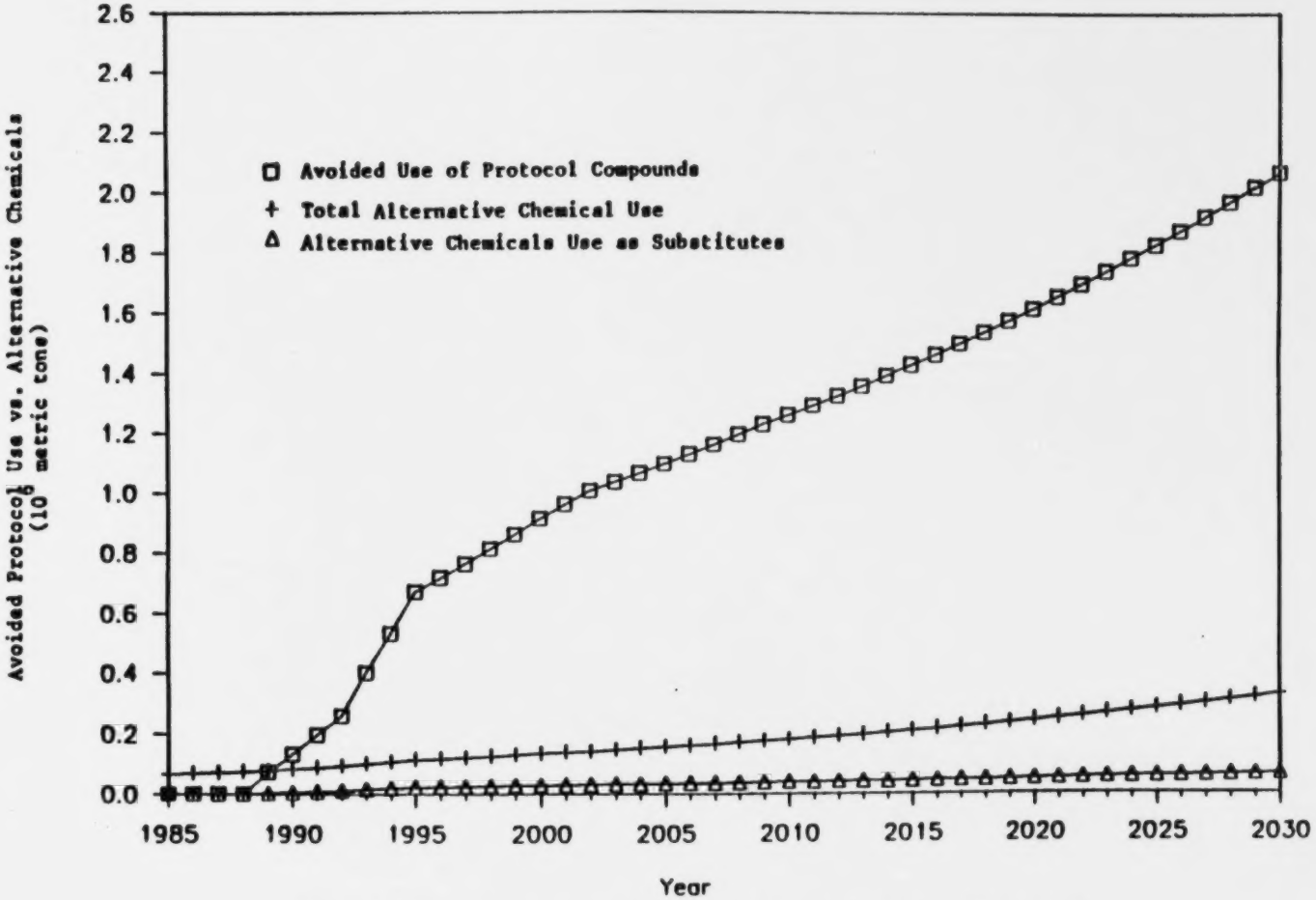


Figure 11. Comparison of Weighted Metric Tons of Protocol Compounds Avoided and Weighted Metric Tons of Alternate Chemicals (Total and Substitute Use)

REFERENCES

1. Regulatory Impact Analysis, Protection of Stratospheric Ozone, Office of Air and Radiation, U. S. Environmental Protection Agency, December 1987.

2. Connell, P.S., "A Parameterized Numerical Fit to Total Column Ozone Changes Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere," in Assessing the Risks of Trace Gases That Can Modify the Stratosphere, Vol. VII, Office of Air and Radiation, U. S. EPA, December 1987.

3. Hammitt, J.K. et al., "Product Uses and Market Trends for Potential Ozone Depleting Substances, 1985-2000," Rand Corp., May 1986.

4. Gibbs, M.J., "Scenarios of CFC Use: 1985-2075" in Assessing the Risks of Trace Gases That Can Modify the Stratosphere, Vol. VI, Office of Air and Radiation, U. S. Environmental Protection Agency, December 1987.

5. SRI International, "CEH Product Review: Fluorocarbons," October 1985.

6. World Meteorological Organization, "Atmospheric Ozone 1985," Report No. 16, Vol. I, 1986.

7. Alliance for Responsible CFC Policy, "Montreal Protocol Briefing Book, " December 1987.